

Linking IIP Technology Development to NASA Aura Satellite Calibration: A Case Study of Isotopes

Sixth Annual
NASA Earth Science Technology Conference
Adelphi, Maryland

June 29, 2006

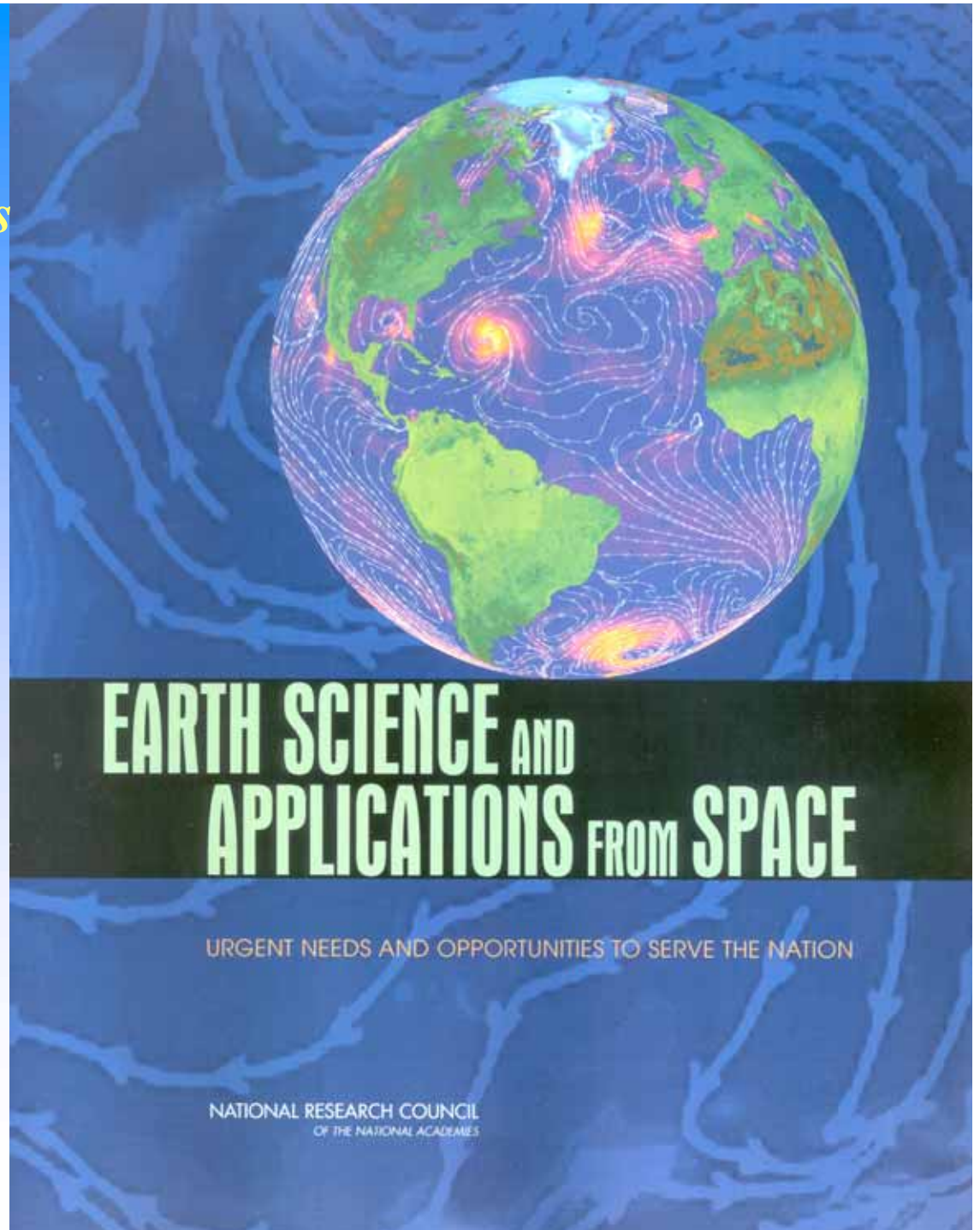
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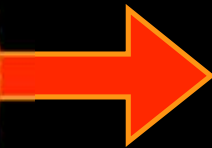
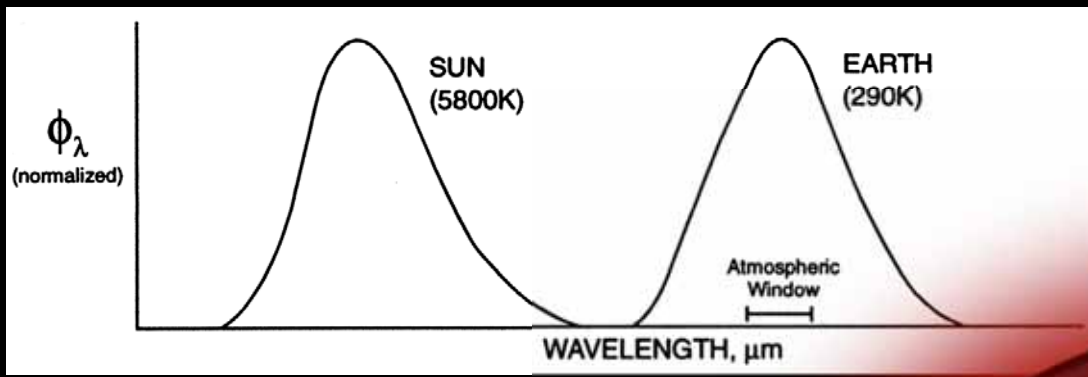
VISION

*A healthy, secure, prosperous
and sustainable society for
all people on Earth*

*“Understanding the complex,
changing planet on which we
live, how it supports life, and
how human activities affect its
ability to do so in the future is
one of the greatest intellectual
challenges facing humanity. It
is also one of the most important
for society as it seeks to achieve
prosperity and sustainability.”*

NRC (2005)





Over the past
50 years

Arctic/Greenland

q

All glaciers
 18×10^{21}
Joules



Ocean

q

200×10^{21}
Joules



Atmosphere

q

7×10^{21}
Joules

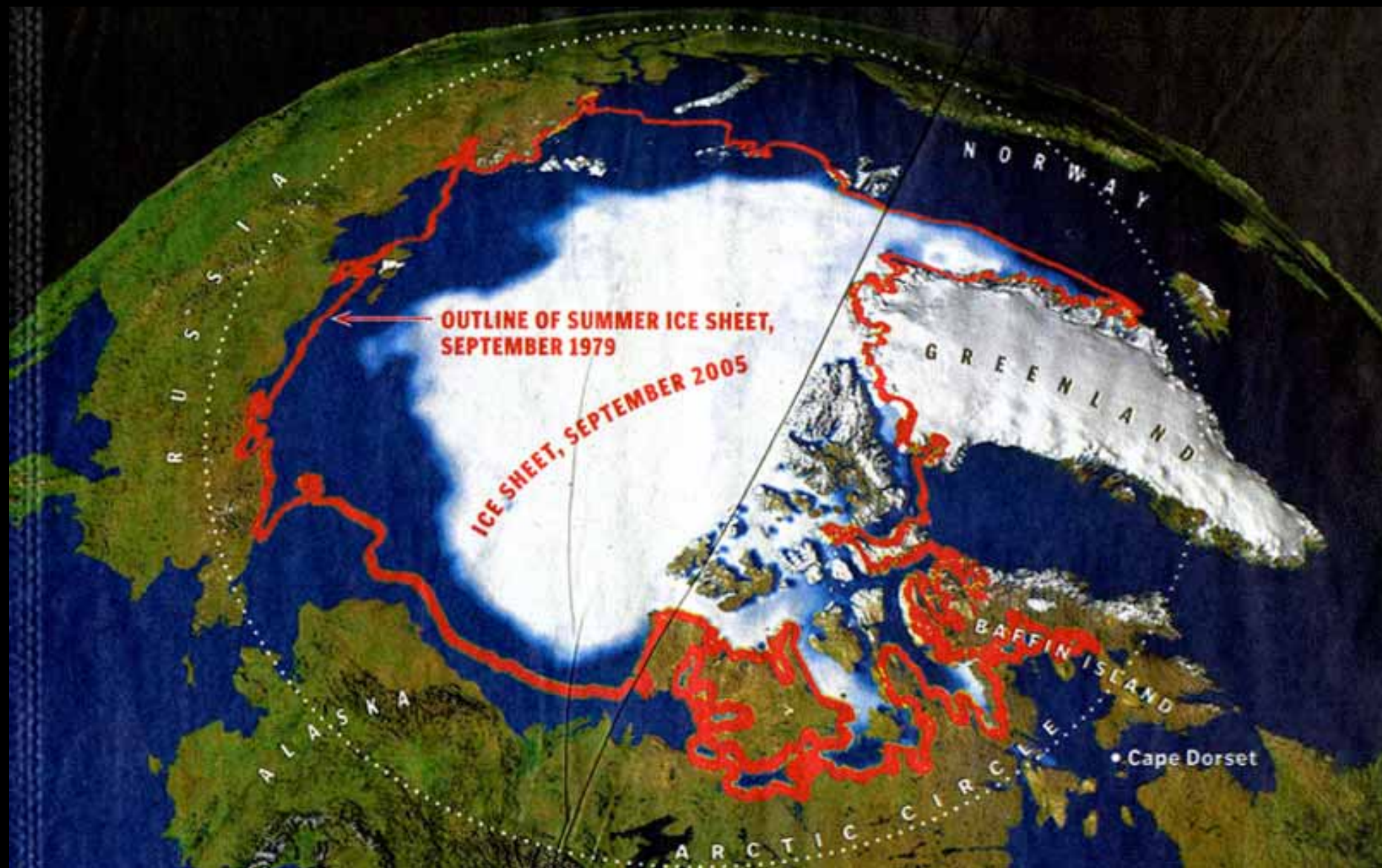


Continental

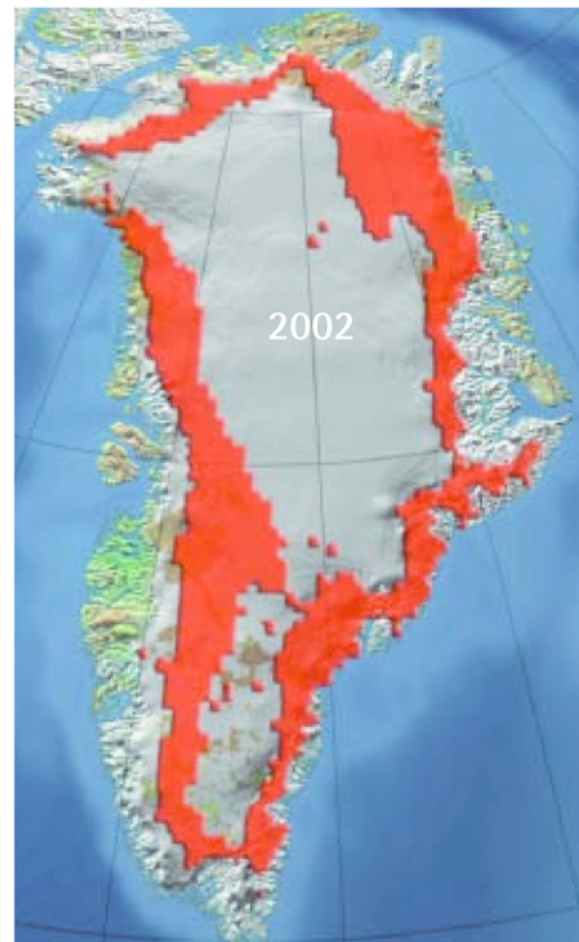
q

9×10^{21}
Joules



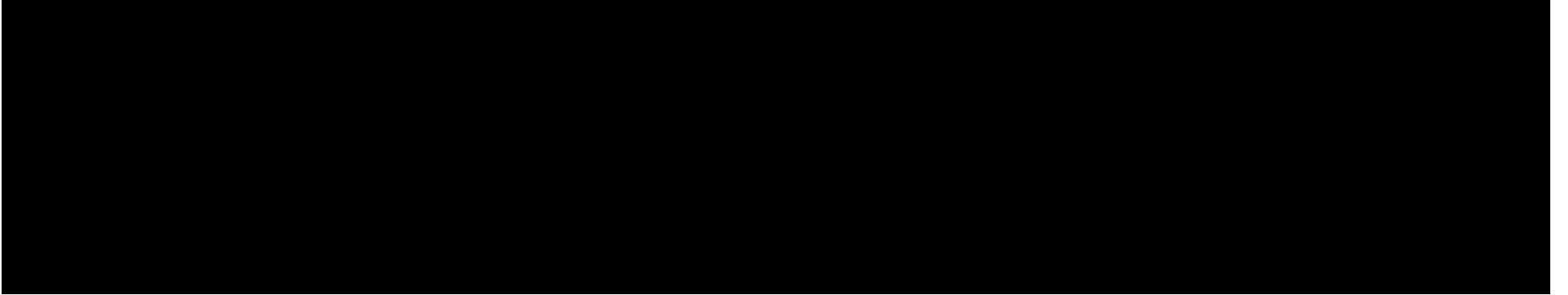
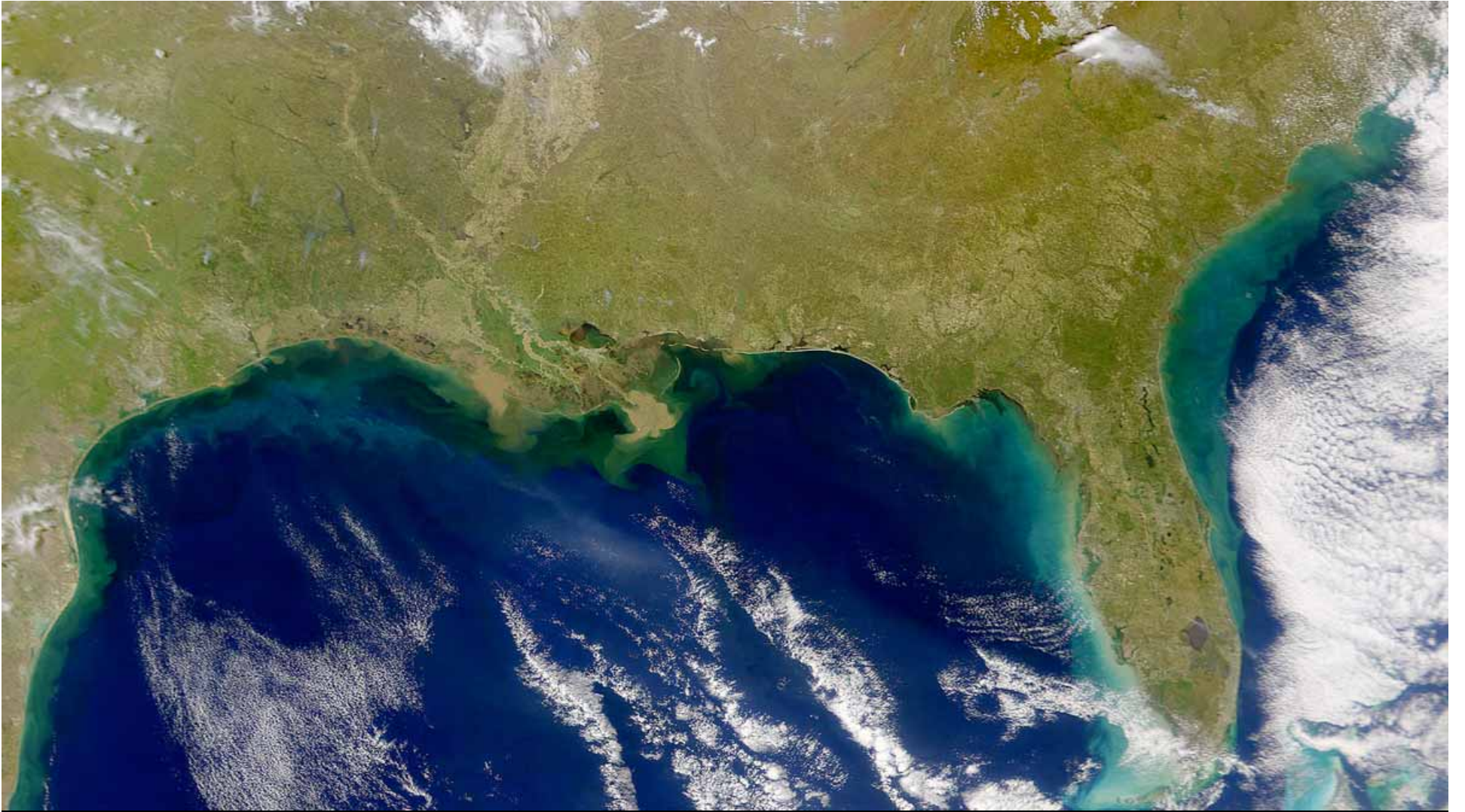


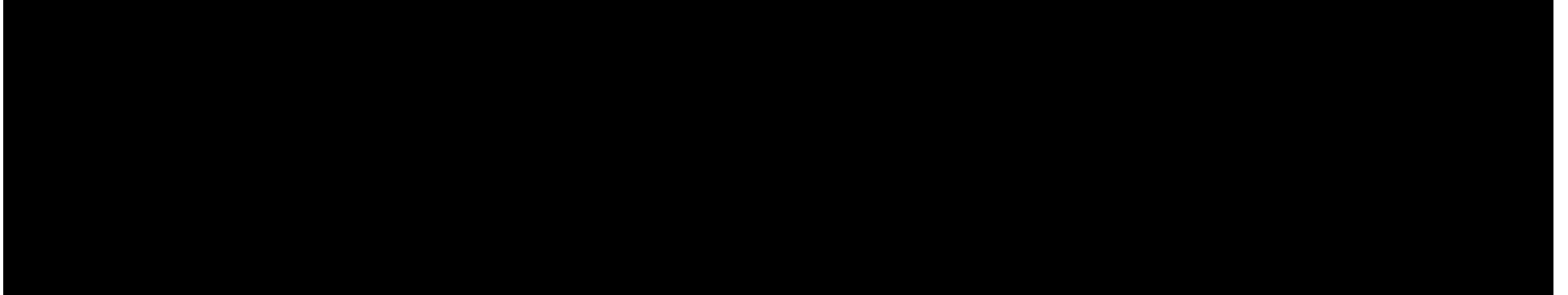
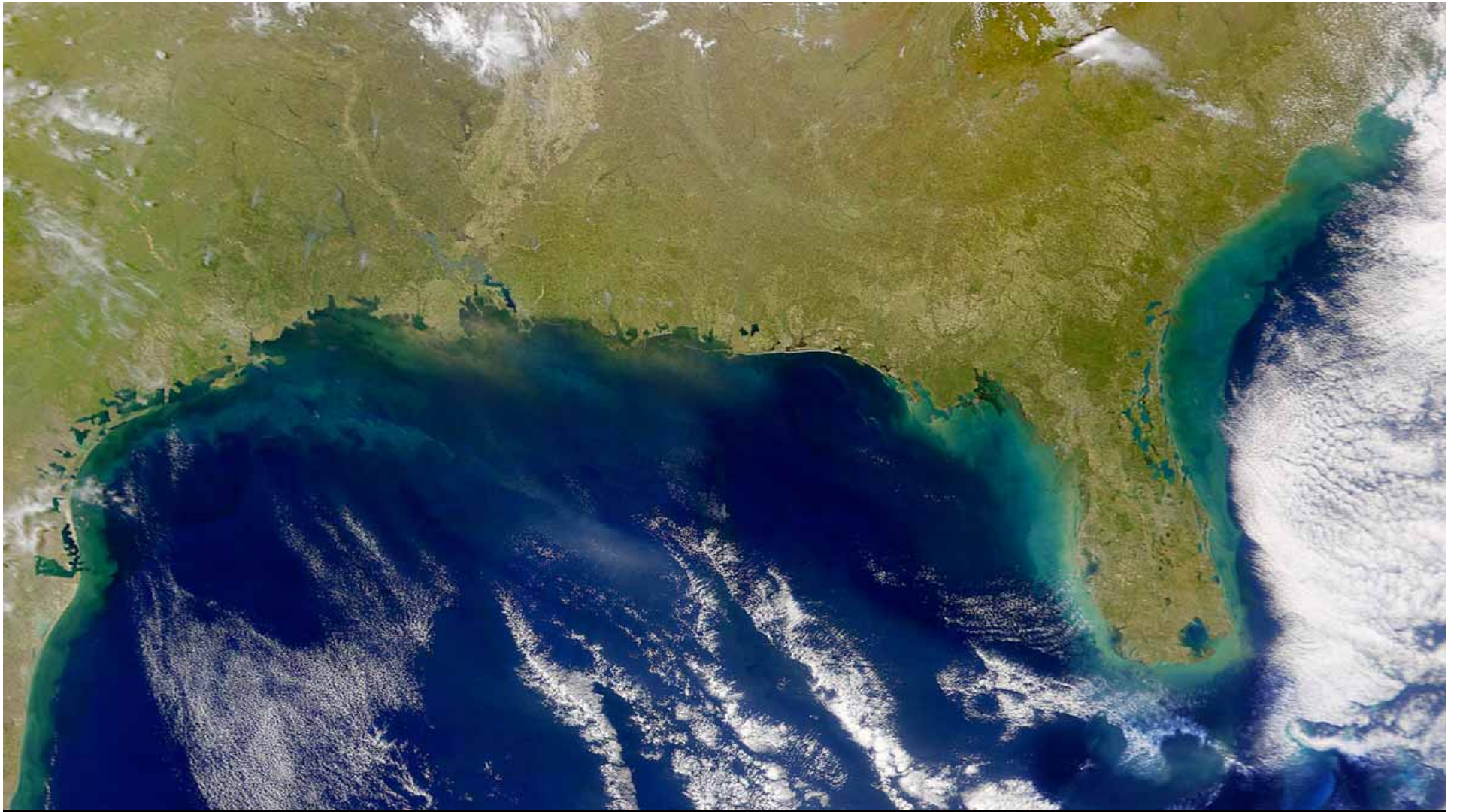
Greenland Ice Sheet Melt Extent

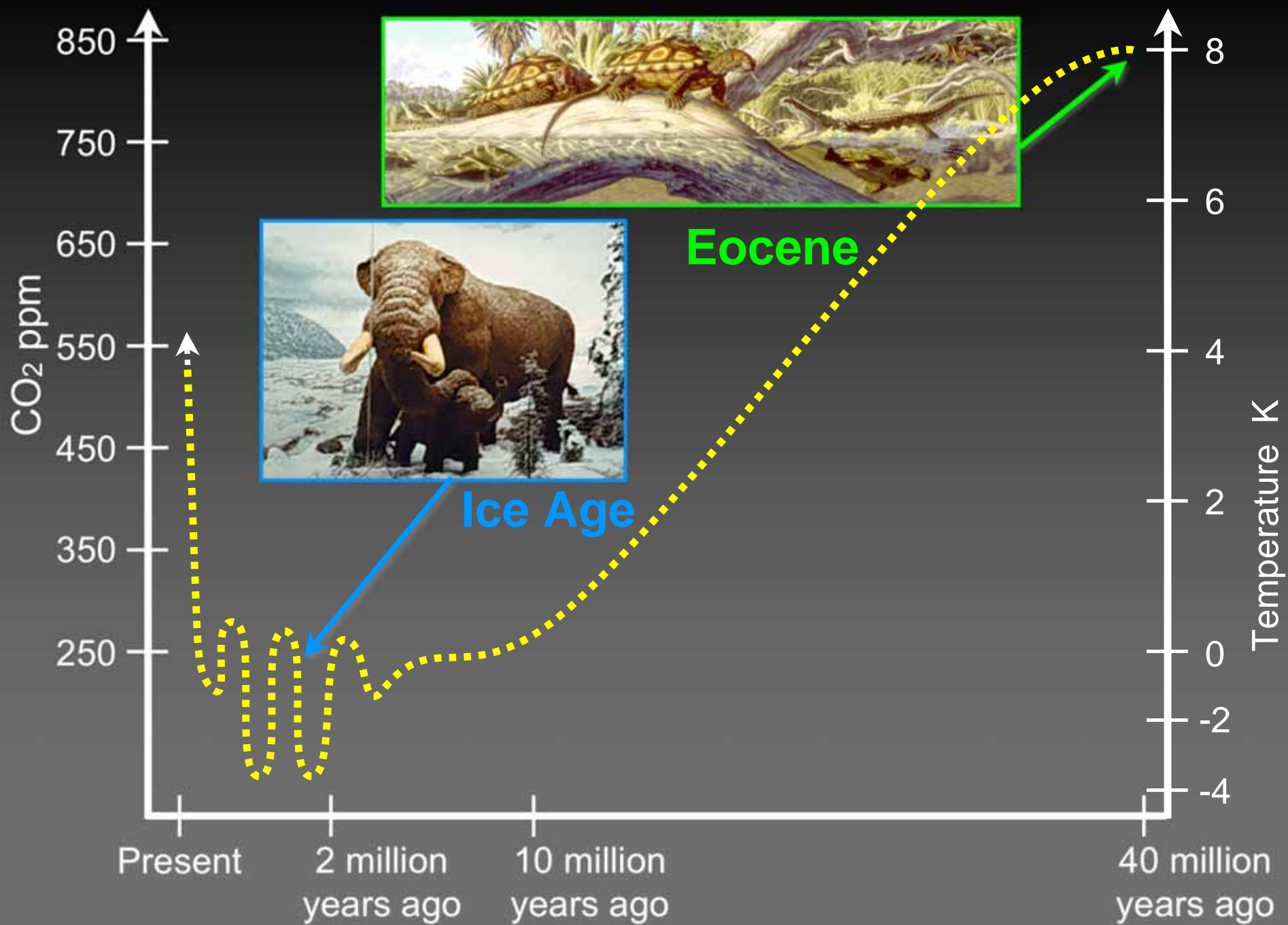


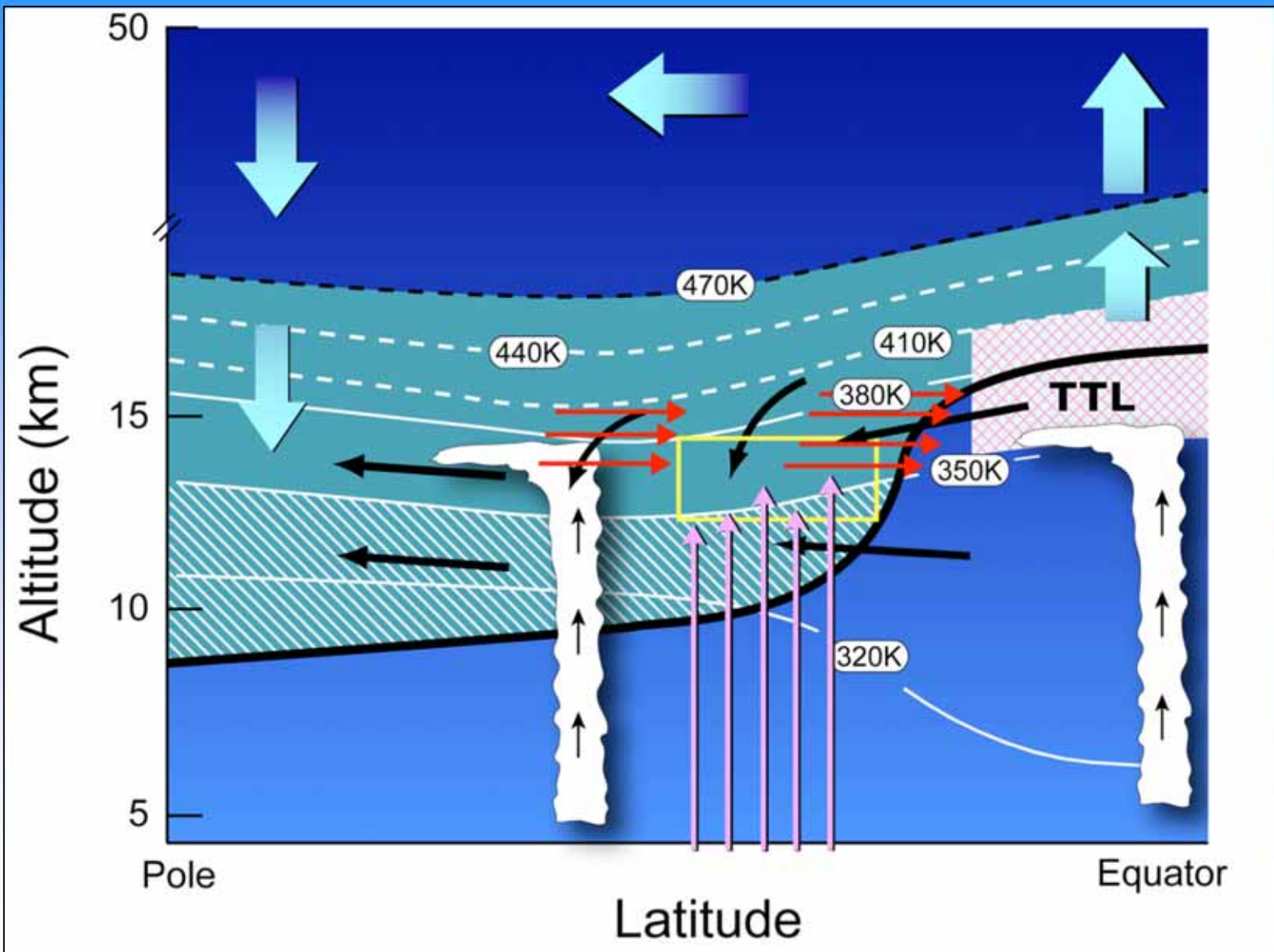








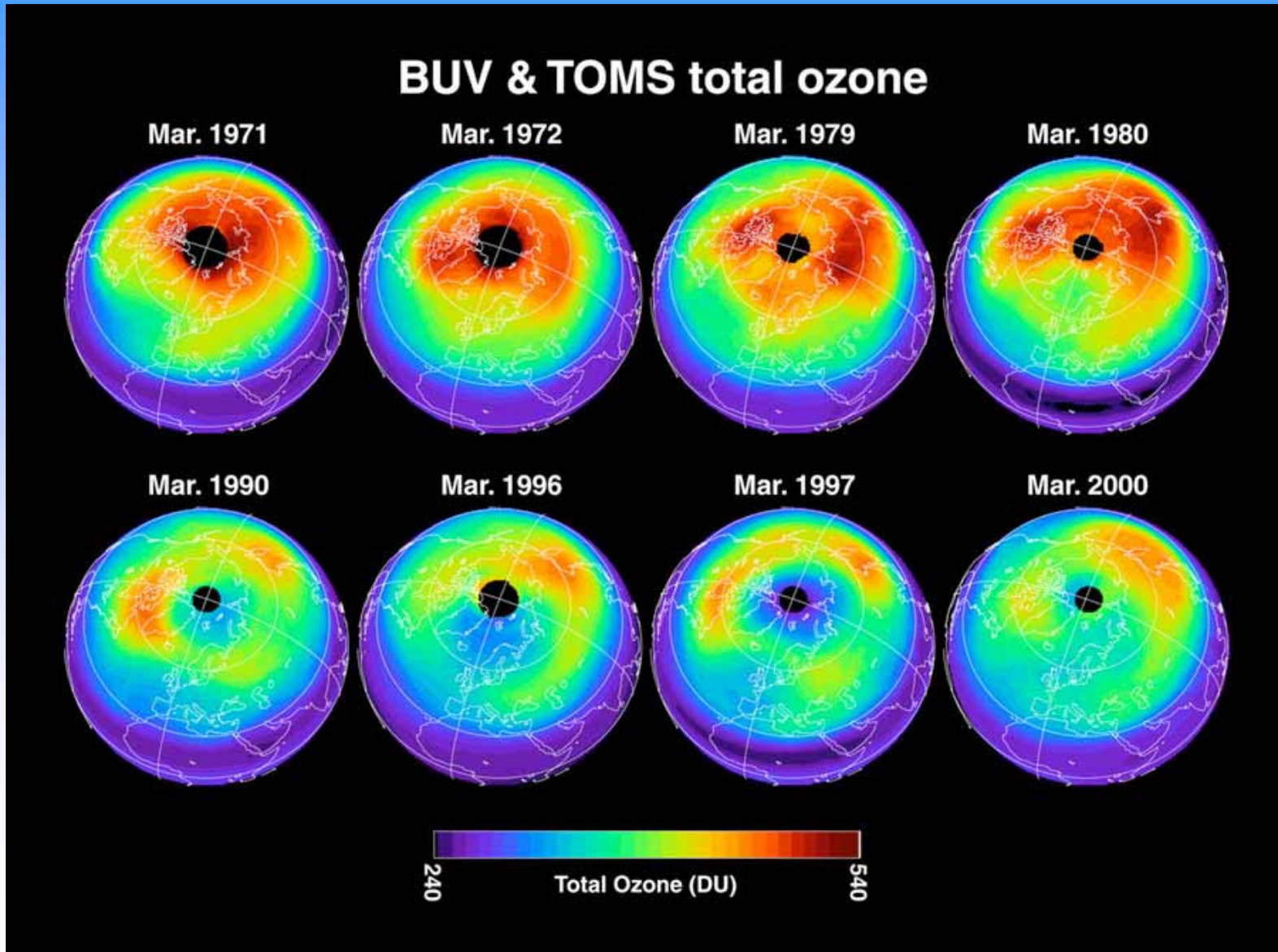




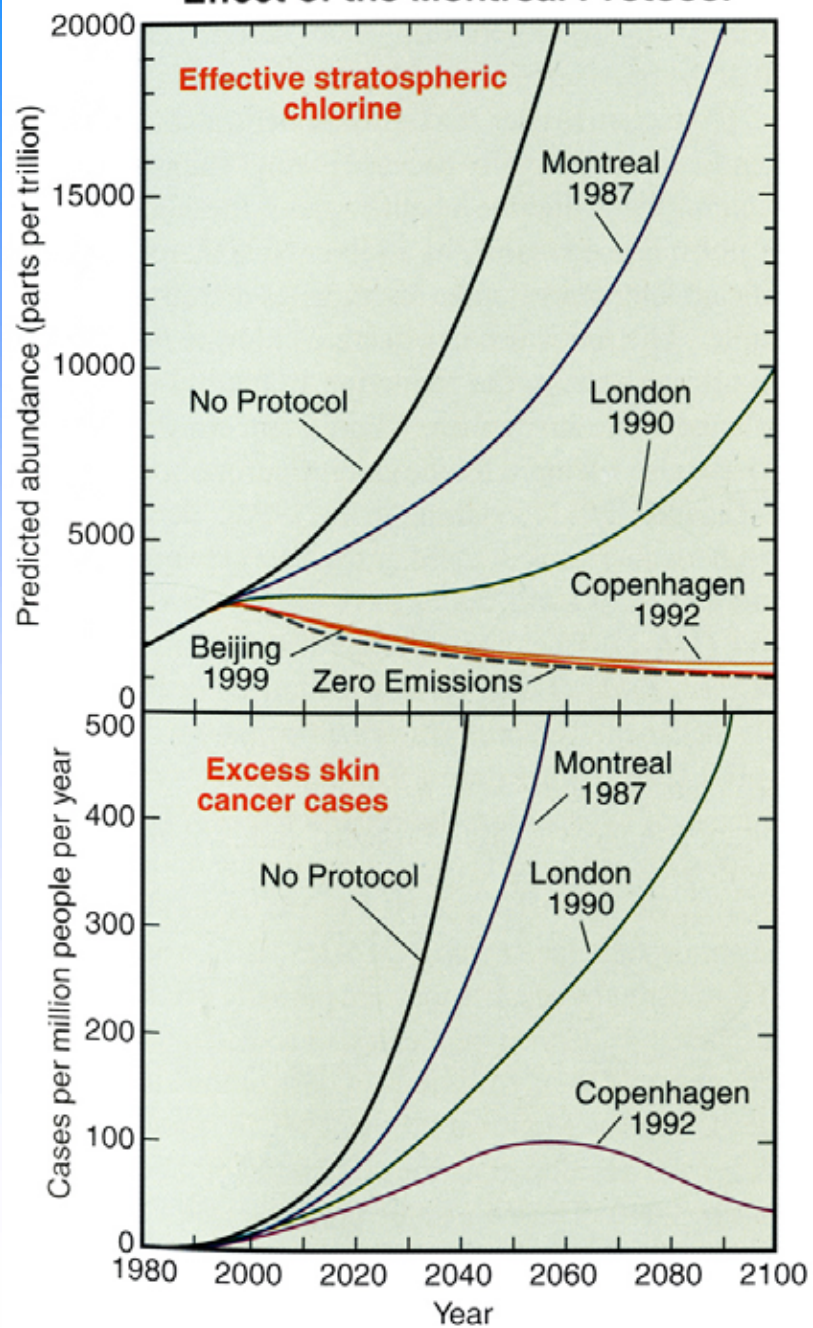
Research Objectives

- Establish the Mechanisms that Control Large Scale Transport in the Atmosphere
 - Trop/Strat Exchange and the Processes that Control Strat Water Vapor
 - How Boundary Condition on Water Responds to Climate Forcing

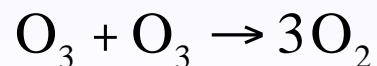
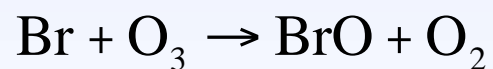
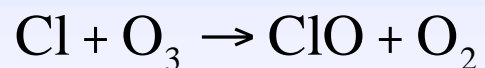
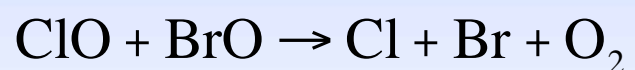
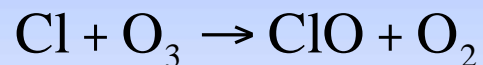
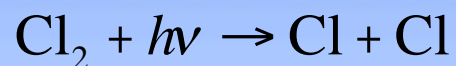
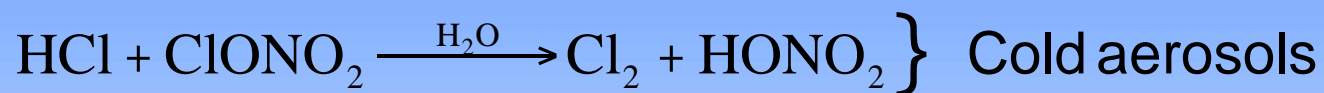
Ozone Loss in Northern Hemisphere from Satellite



Effect of the Montreal Protocol



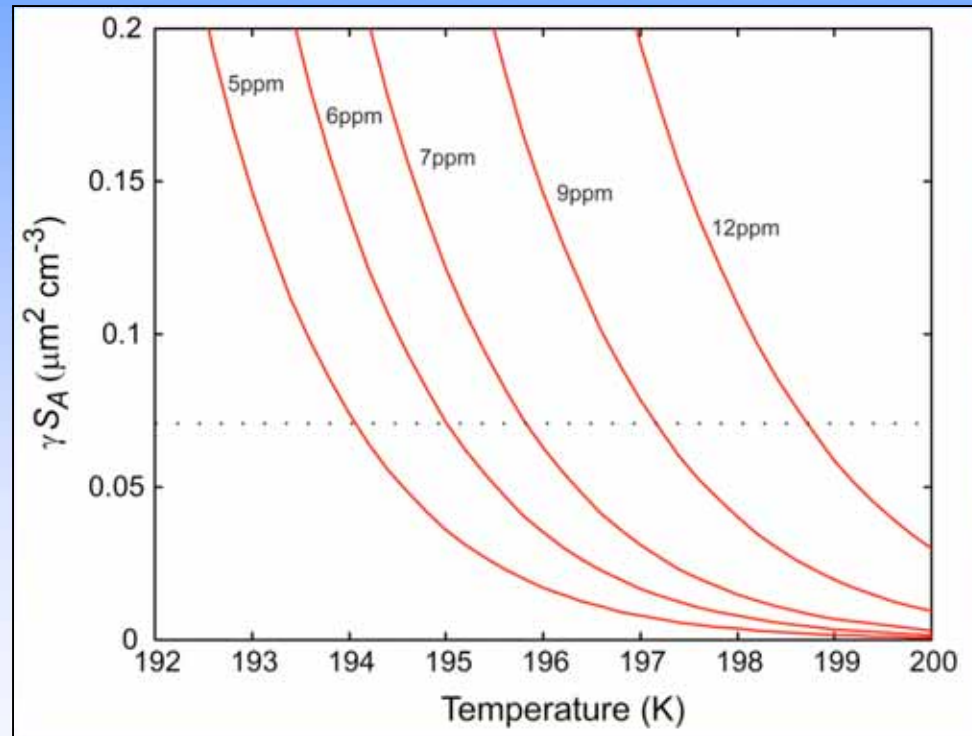
The Coupling of Ozone Loss and Climate



} Coupling of Chlorine and Bromine

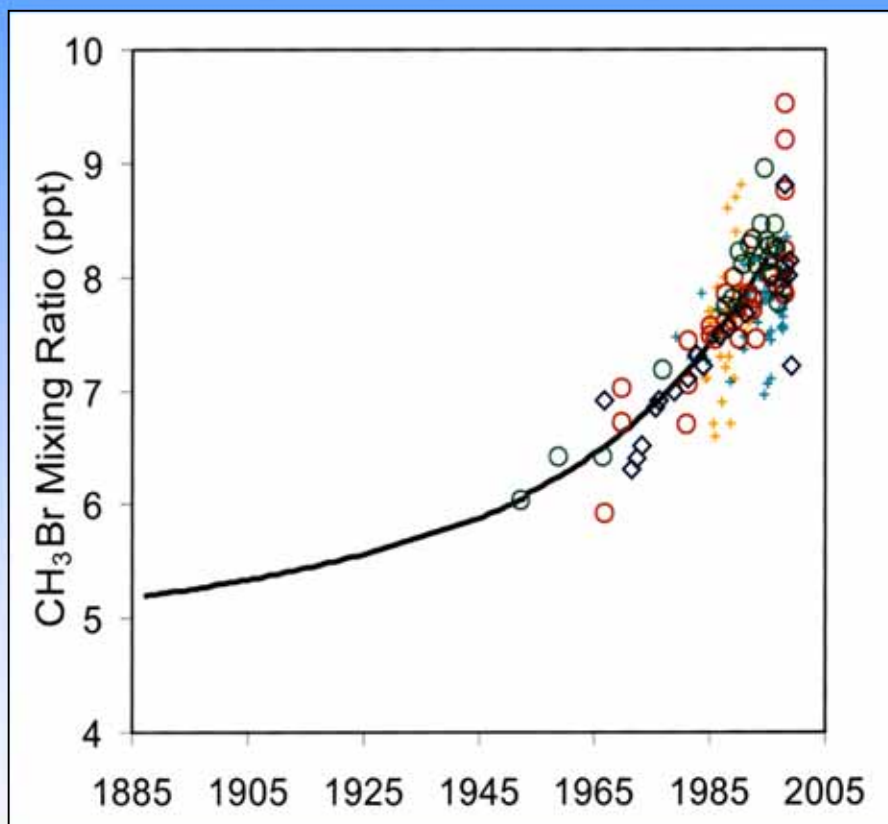
Linking Climate Change to Ozone Destruction

- Future ozone loss is not simply a function of chlorine loading



Potential impact of climate change on water vapor in the atmosphere raises the threshold temperature for halogen activation.

Why Measure Bromine?



Methyl bromide is the largest atmospheric bromine source.

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ENVIRONMENTAL POLICY

CHEMICAL
& Engineering News

METHYL BROMIDE PHASEOUT STYMIED

After falling for many years, U.S. consumption of the ozone-depleting fumigant may be rising

HEALTHY HARVEST California ranchers prepare their strawberry field for research on alternatives to methyl bromide.
PHOTO BY SCOTT BAUER/USDA

Future levels of bromine in the atmosphere may increase.

Research Objectives

- Establish the Mechanisms that Control Ozone in the Stratosphere and Troposphere
 - Balance Between Chemical and Dynamical Control of Ozone in the Lower Stratosphere
 - Cause of Ozone Erosion in the Lower Stratosphere
 - Impact of Ozone on Tropopause Boundary Condition
 - Forecast of UV Dosage Level in the next Decade, Two Decades.
 - Union with Medical Community to Forecast Human Health Impact

**STRATEGY: USE IIP TECHNOLOGY TO
ADDRESS TWO PROBLEMS – BOTH
CRITICAL FOR CLIMATE RESPONSE TO
FORCING**

- 1. The issue of absolute water vapor concentrations and the large disparity between satellite and *in situ* concentrations
- 2. The introduction of isotopic tracers to diagnose mechanistic structure of strat/trop exchange

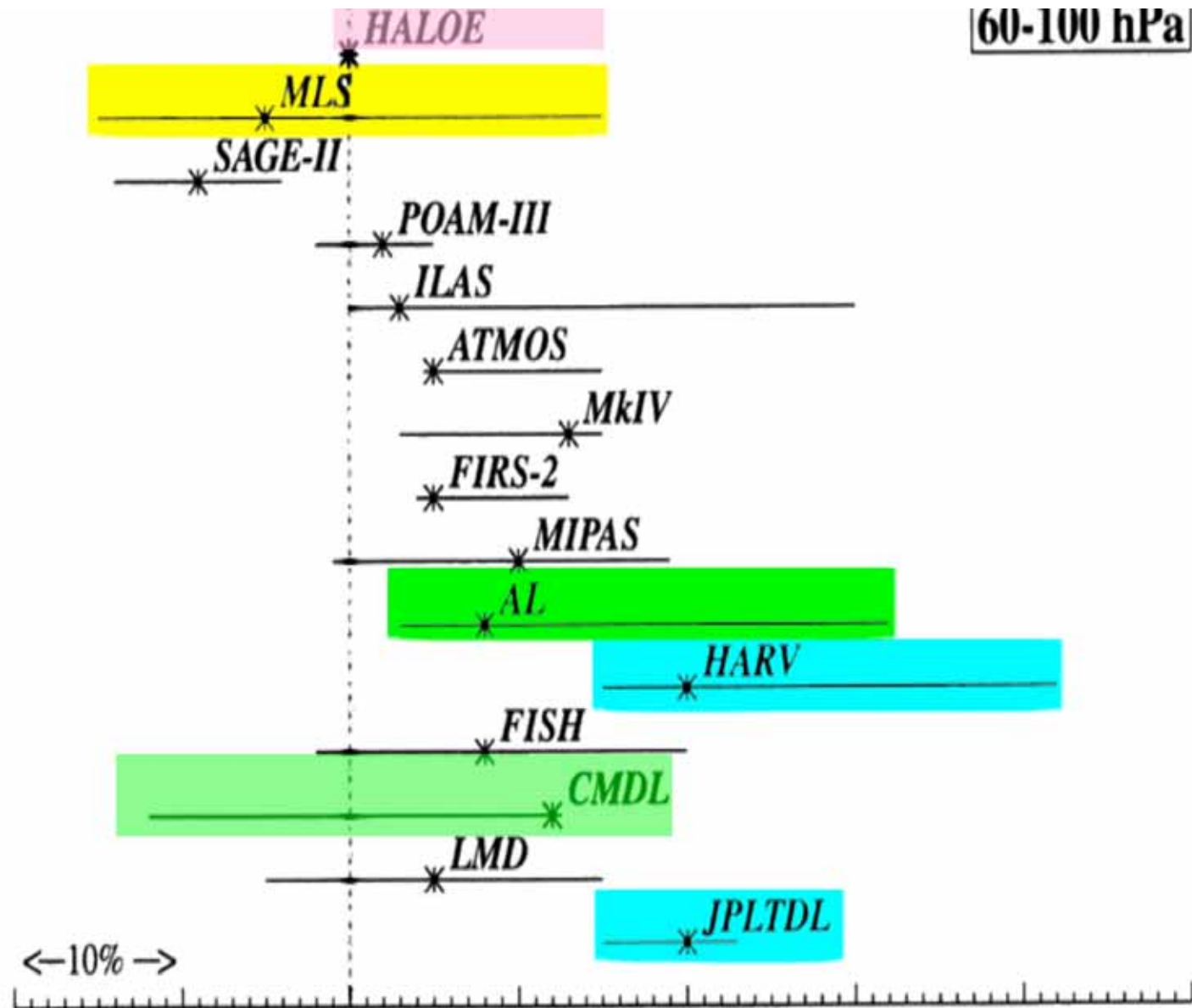


Figure 1. Summary of intercomparison relationships summarized in the 2000 SPARC report. Symbols give % difference from HALOE. Horizontal lines show range of intercomparisons.

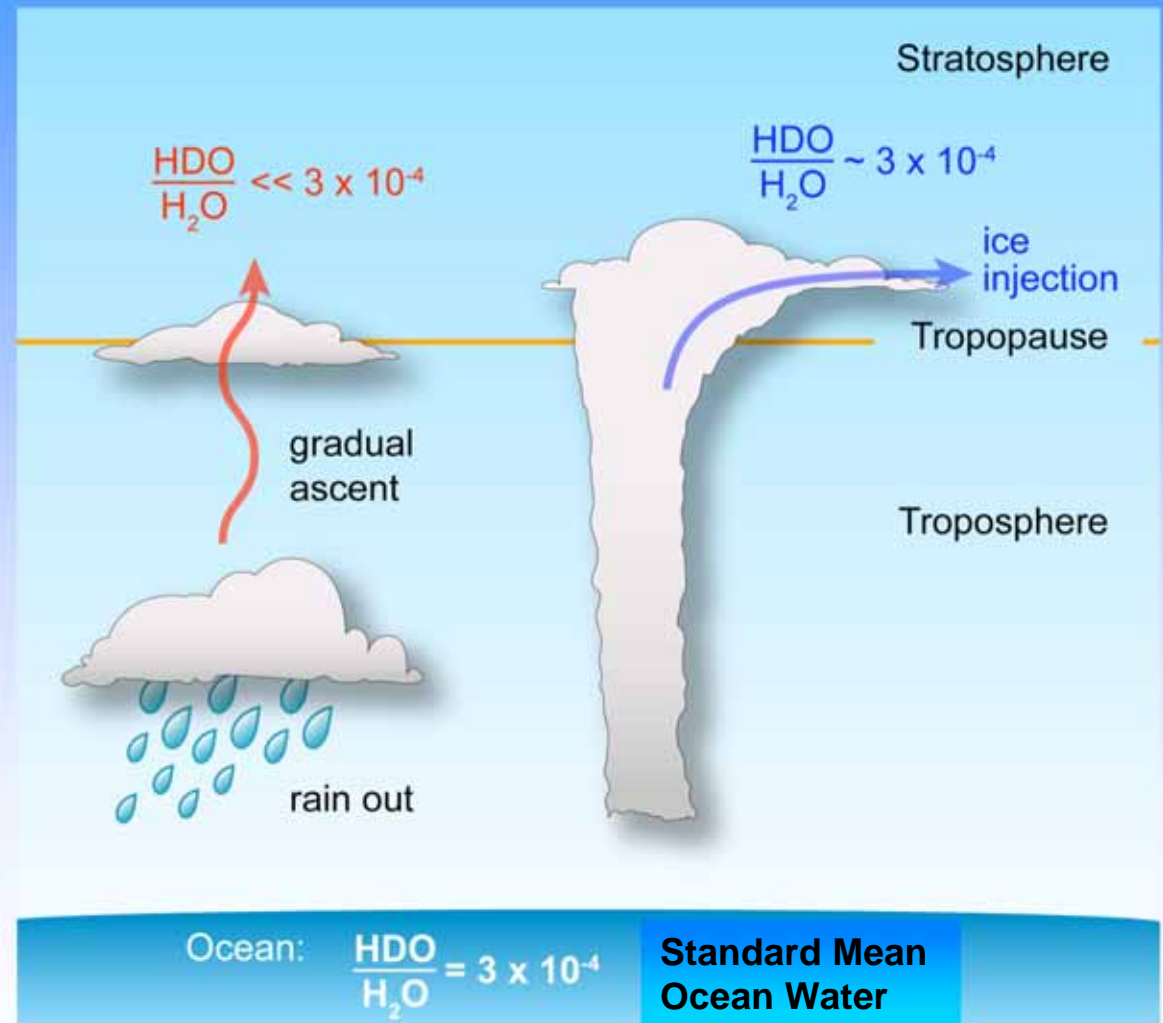


Aura Launch : July 15, 2004
Vandenberg Air Force Base, CA



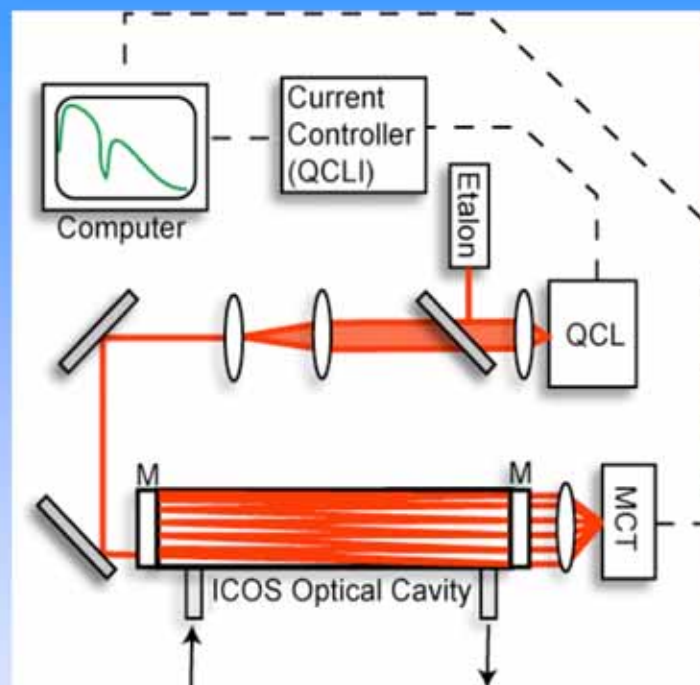
Water isotopes as tracers of Convection

- HDO condenses more readily than H₂O
- Rainout leads to HDO depletion
- Ice injection can make the stratosphere “Heavy”
- *In situ* water isotope measurements can offer a tracer for the condensation history of air parcels



$$\delta D = 1000 \left(\text{HDO}/\text{H}_2\text{O}/\text{SMOW} - 1 \right)$$

Integrated Cavity Output Spectroscopy (ICOS)



Quantum Cascade Laser (100 mW)

1 meter cavity with 4" mirrors

High-finesse Optical Cavity (215ppm mirrors)

$\tau = 14 \mu\text{s} \rightarrow L_{\text{eff}} = 4.5 \text{ km}$

Calibration tied to laboratory measurements
of absorption cross-section

High Signal to Noise (SNR = 30 at 5ppm)

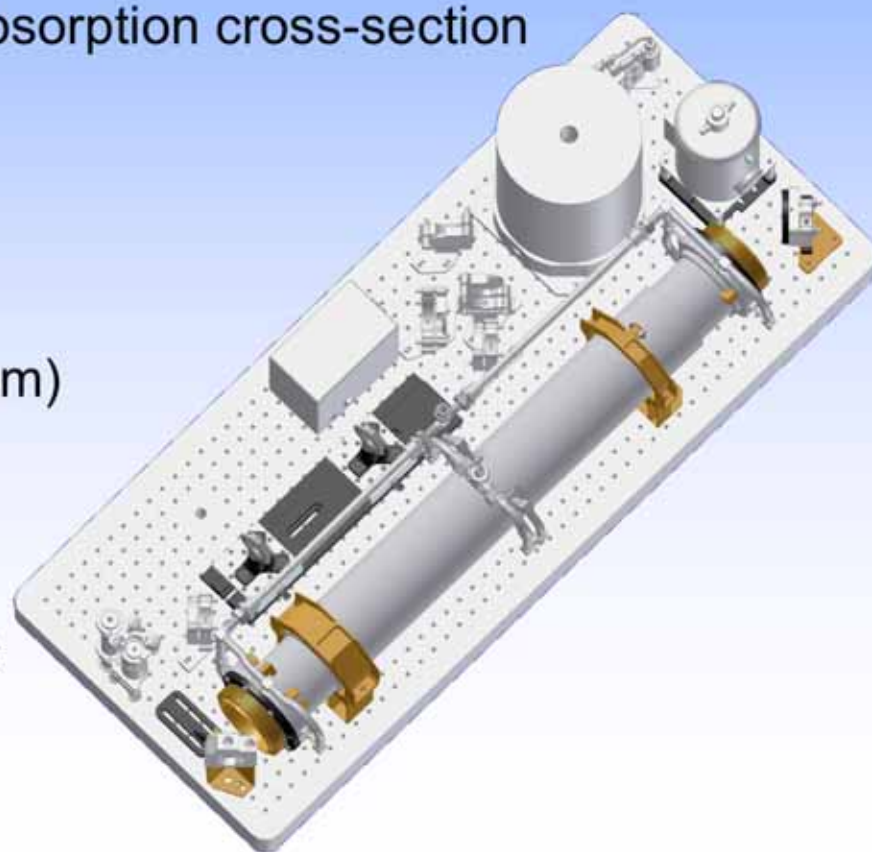
Precision

Accuracy:

Optical stability

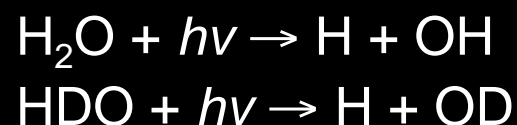
Less susceptible to optical artifacts

In flight cals/diagnostics



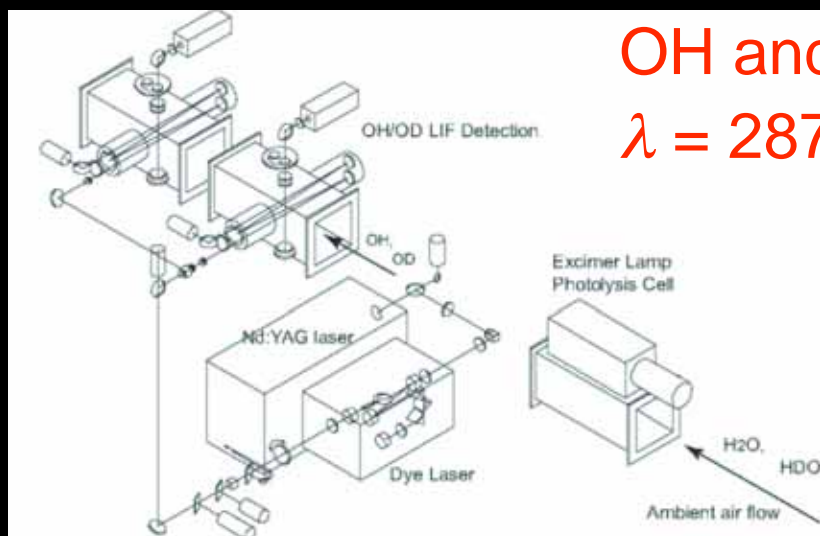
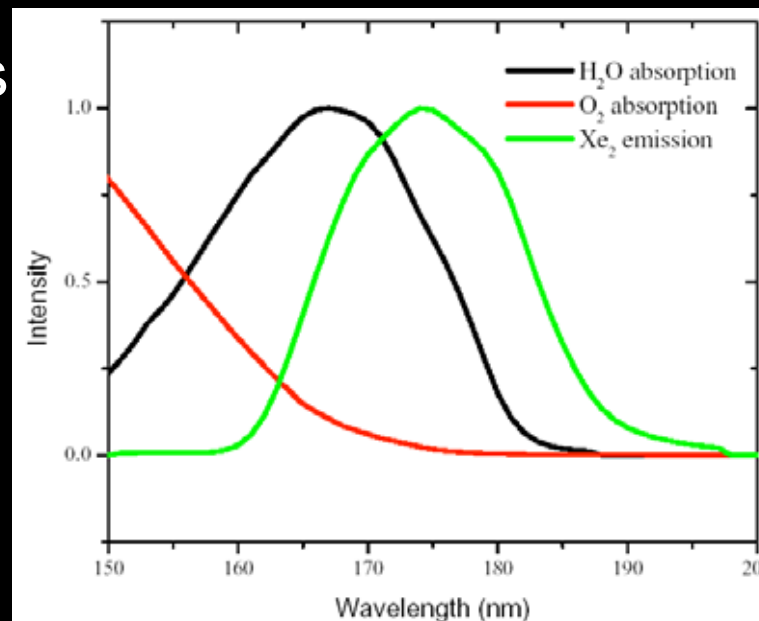
HOx isotopes: Photolysis - Fluorescence detection of HDO/H₂O

Excimer Lamp Photolysis

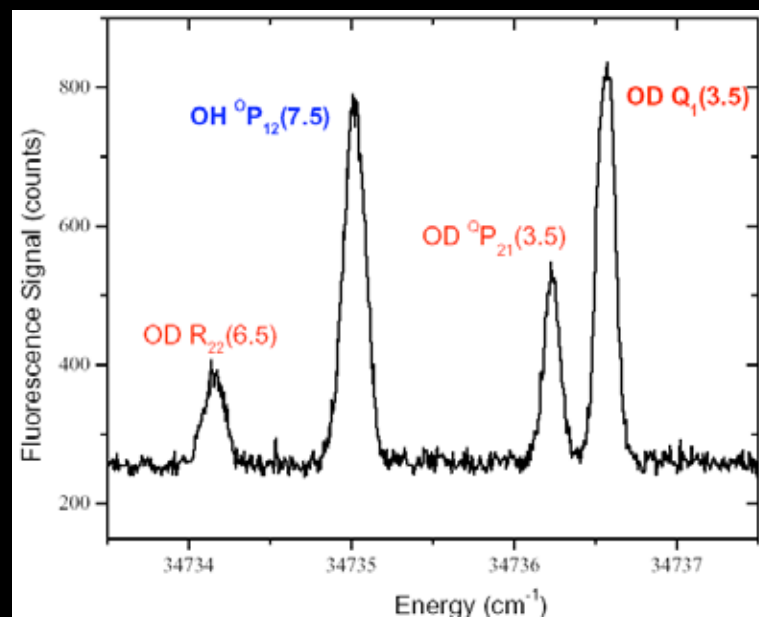


$$h\nu = 8\text{W}$$

$$\lambda = 172\text{ nm}$$

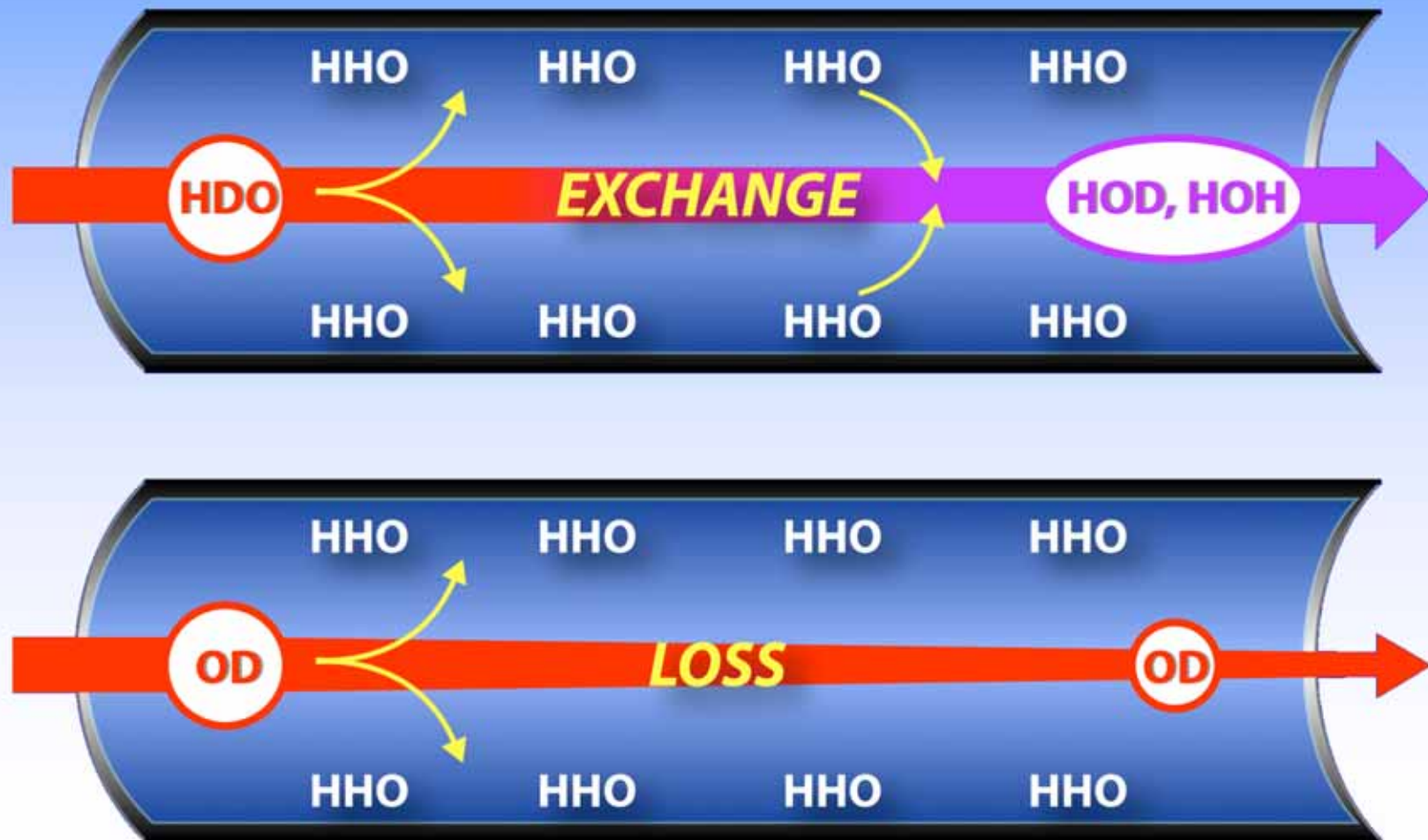


OH and OD LIF
 $\lambda = 287\text{ nm}$



Radical vs. Molecular Sampling

Molecular water exchanges with walls. OH and OD radicals are lost irreversibly



Extensive and intensive laboratory calibrations Using SI traceable standards

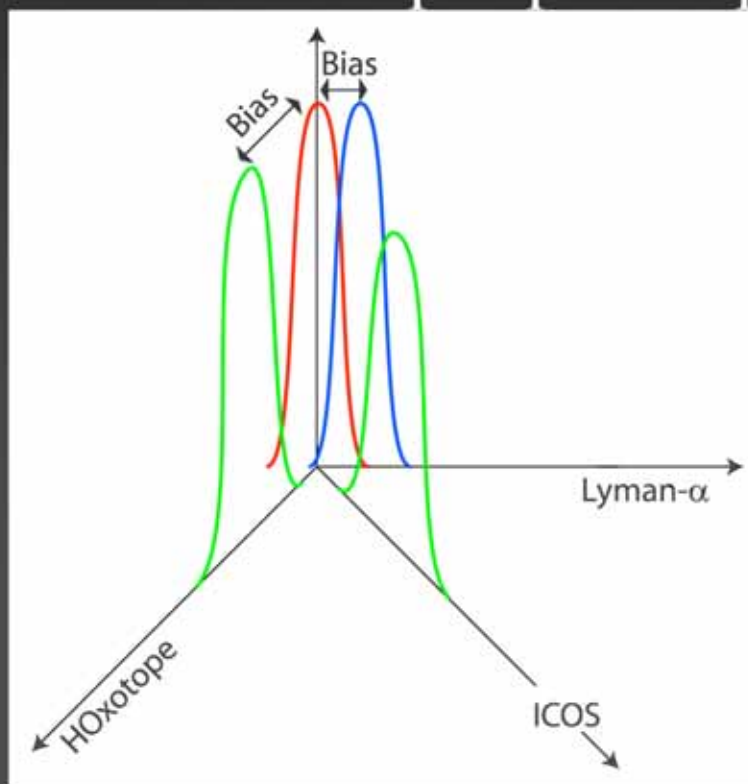
Lyman alpha water vapor and total water

ICOS

HOxotope

Lyman alpha → Water vapor partial pressure

Axial and
radial
absorption at
121.6 nm

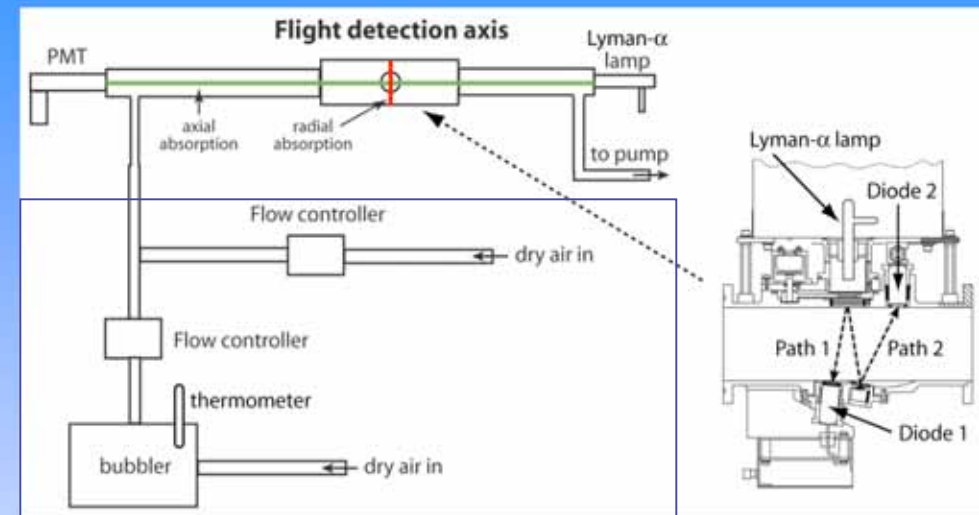
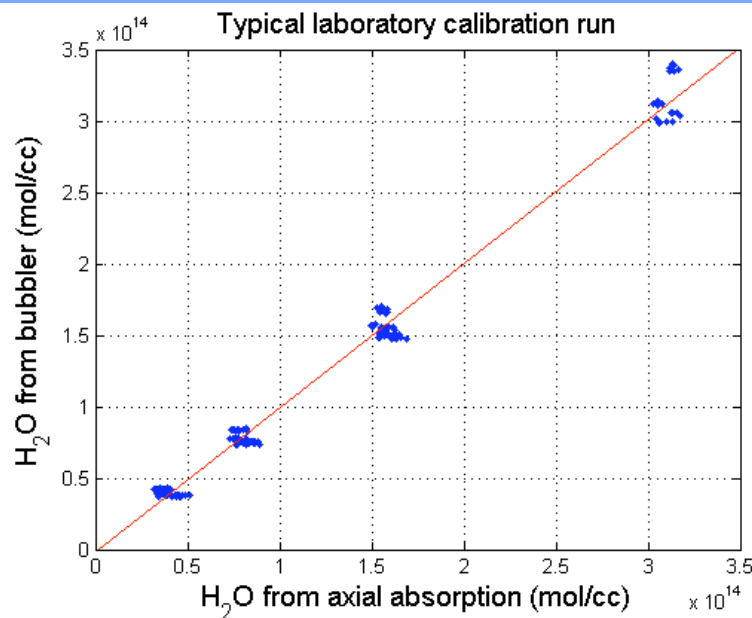


ICOS HOxotope

Droplet
injection

Overview of water vapor instrument accuracy

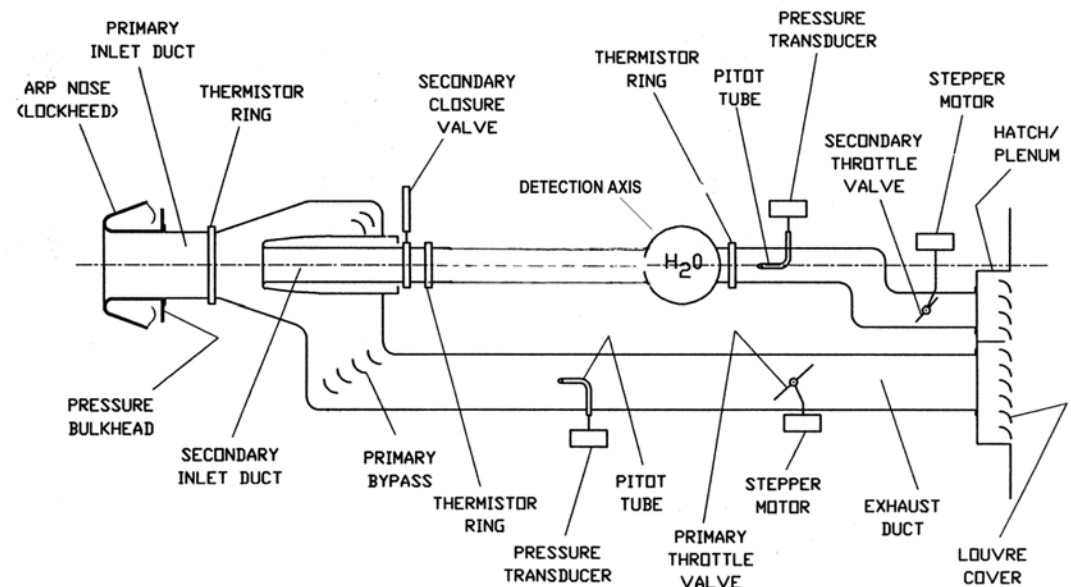
$$WV_{bub} = \frac{[H_2O]}{M} = \frac{P_{H_2O}}{P_B} \frac{\phi_h}{\phi_h + \phi_d}$$



Water vapor source

Ambient air

Water vapor source



Ly- α Water Vapor
 H_2O



HOxotope
 H_2O , HDO



ICOS
 H_2O , HDO, H_2^{18}O , CH_4



Ly- α Total Water
 H_2O (vapor + condensate)

Water measurements during AVE-WIIF

Harvard Lyman- α
water vapor

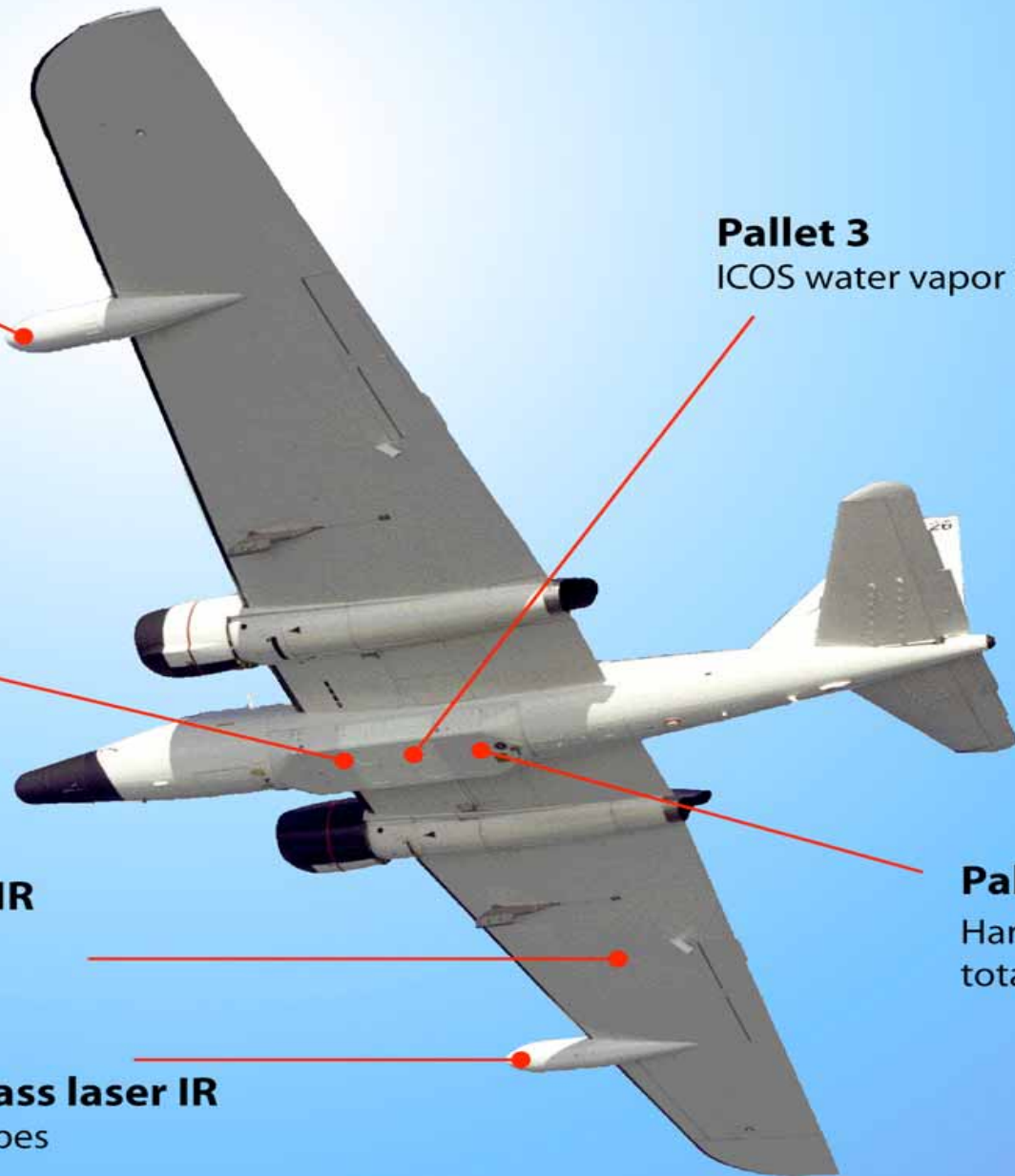
Pallet 3
ICOS water vapor isotopes

Pallet 2
HOxotope
water vapor
isotopes

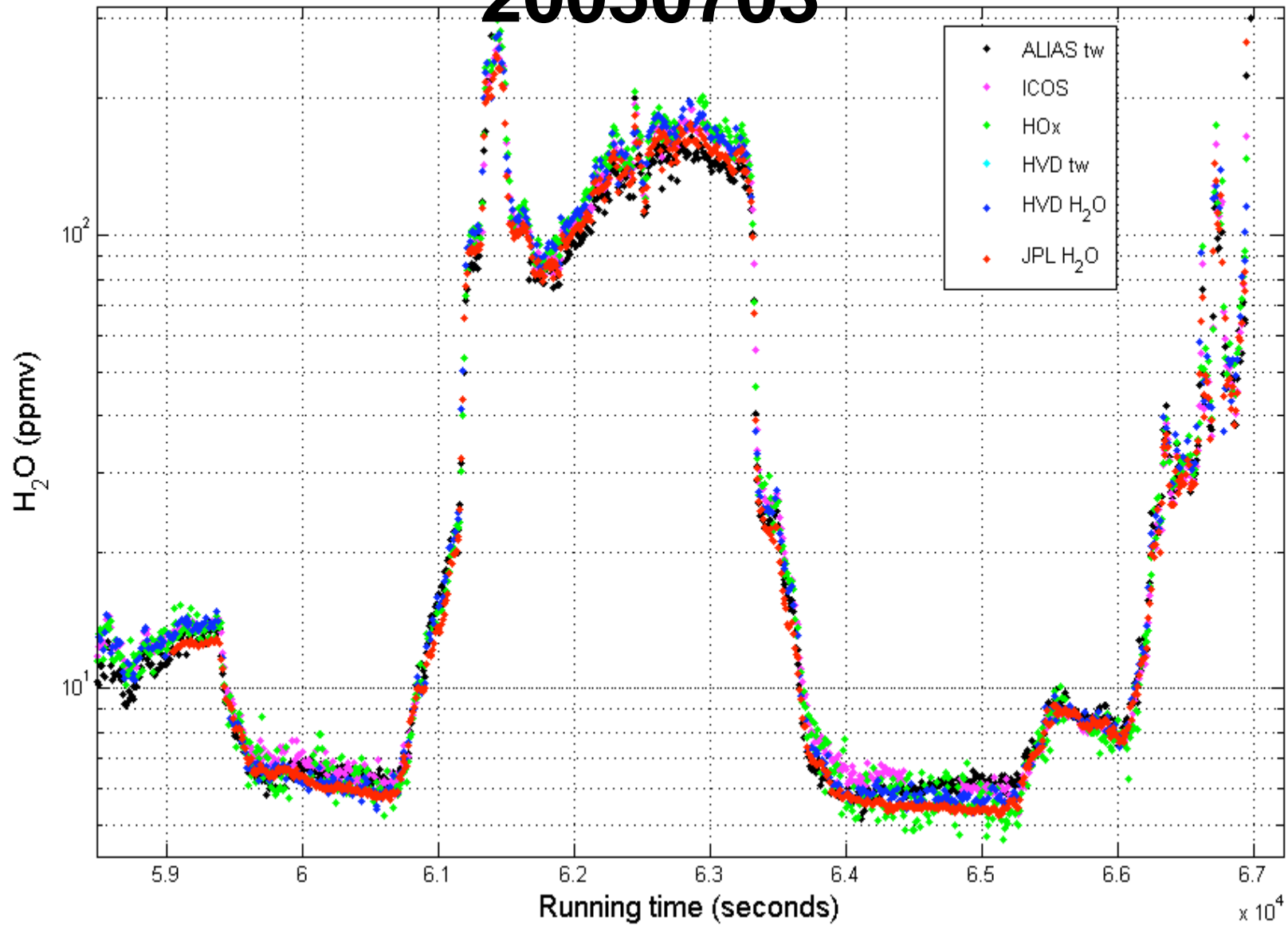
JLH multipass laser IR
water vapor

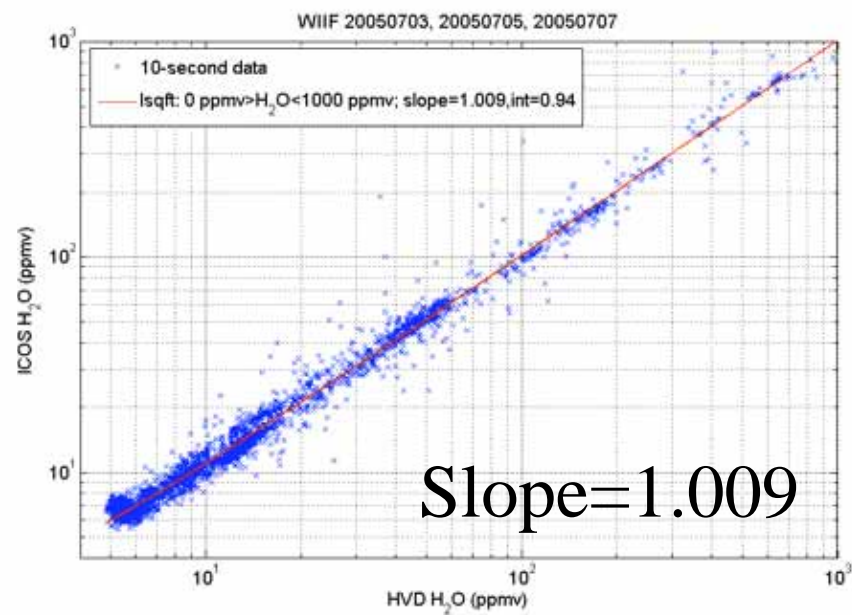
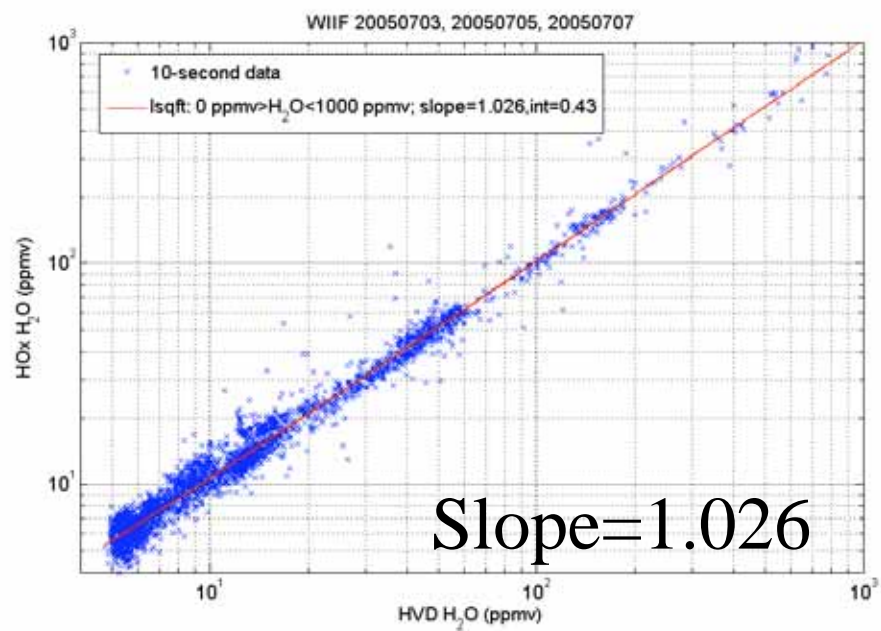
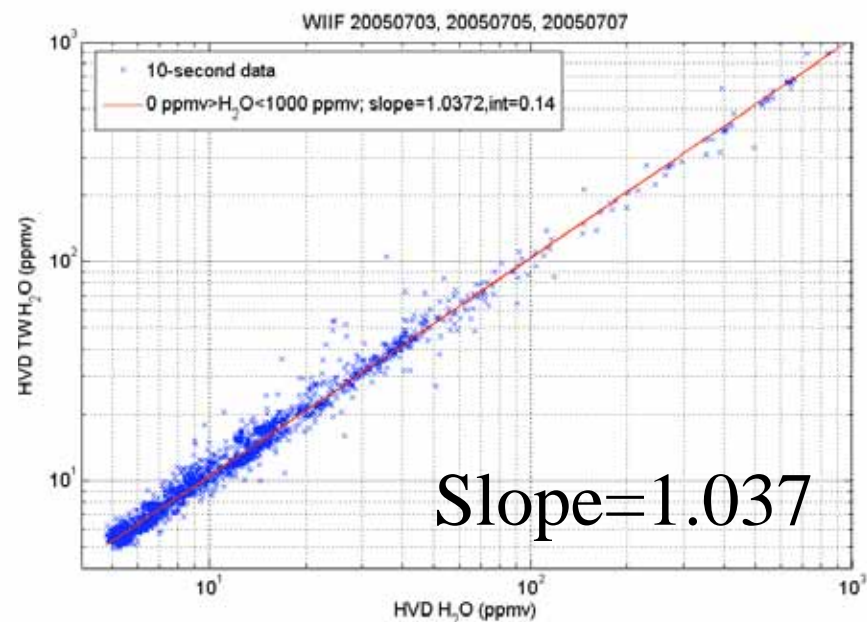
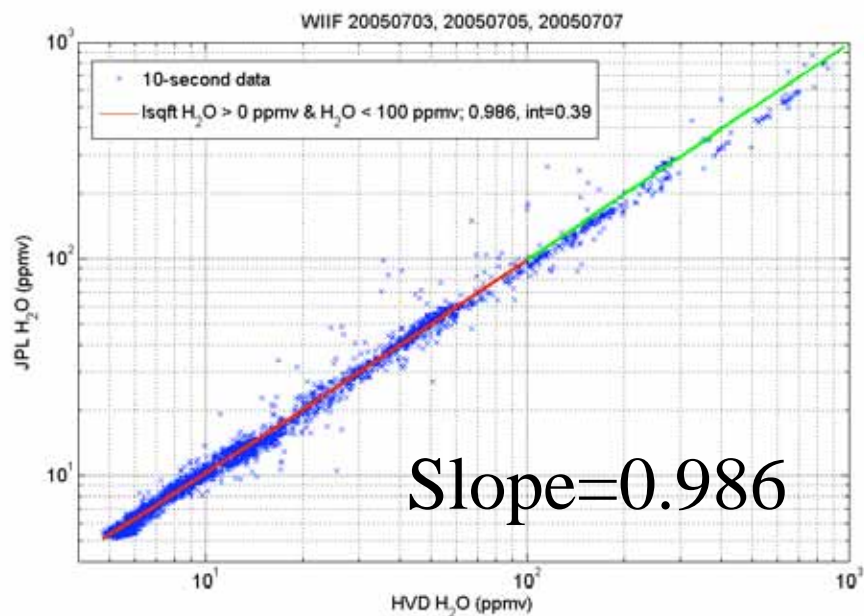
Pallet 4
Harvard Lyman- α
total water

ALIAS multipass laser IR
total water isotopes

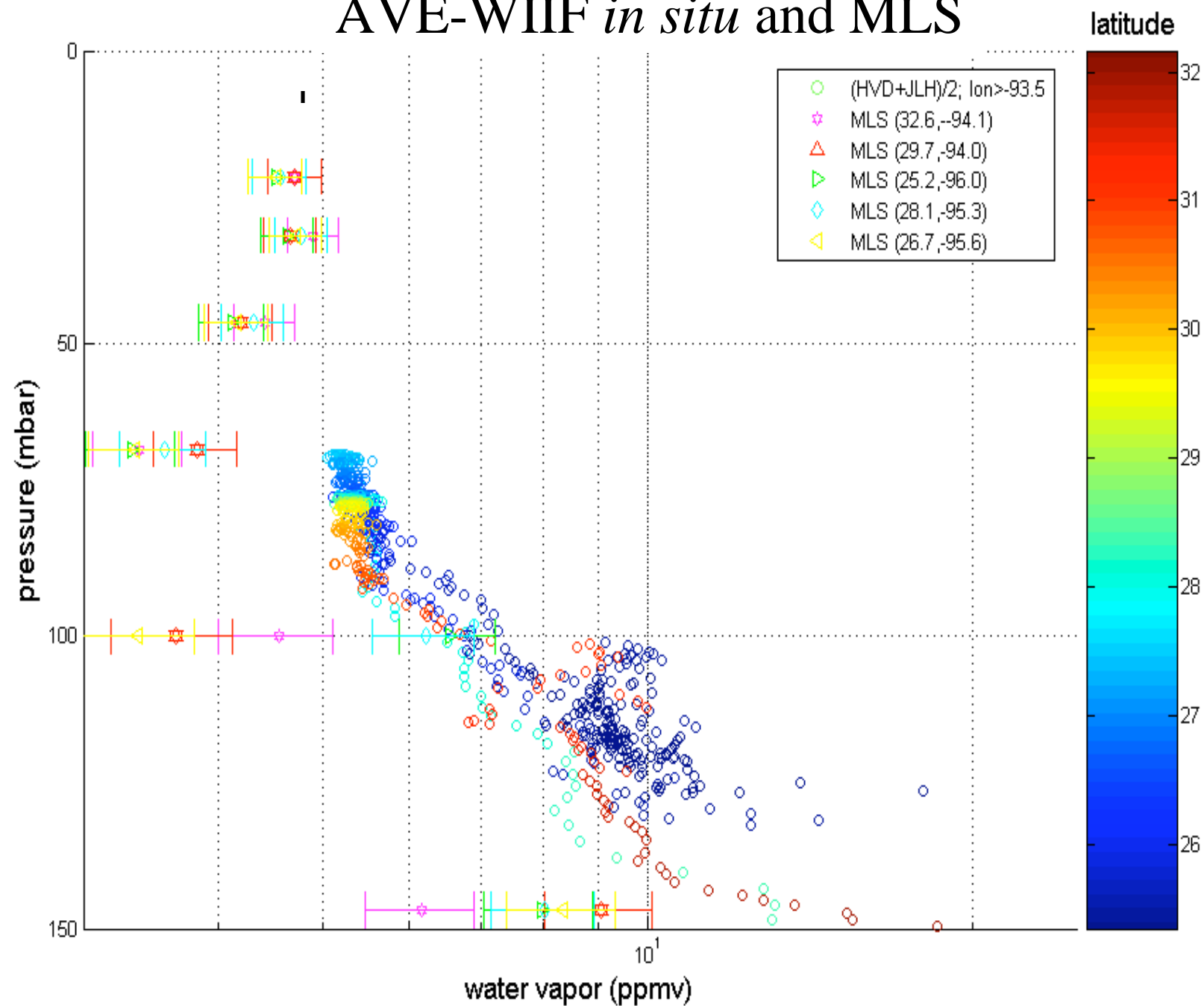


H₂O on 20050703





AVE-WIIF *in situ* and MLS



Take home messages from AVE-WIIF regarding water vapor measurements on the WB57

- Agreement among these *in situ* instruments is consistent with their quoted accuracy from the mid- troposphere to lower stratosphere.
- Satellite instrument validation efforts require high quality water vapor measurements with corroborated accuracy during all AVE deployments.
- Measurements of stratospheric water vapor ***used for trend measurements*** need to have traceability to SI standards.

Calibration/Validation

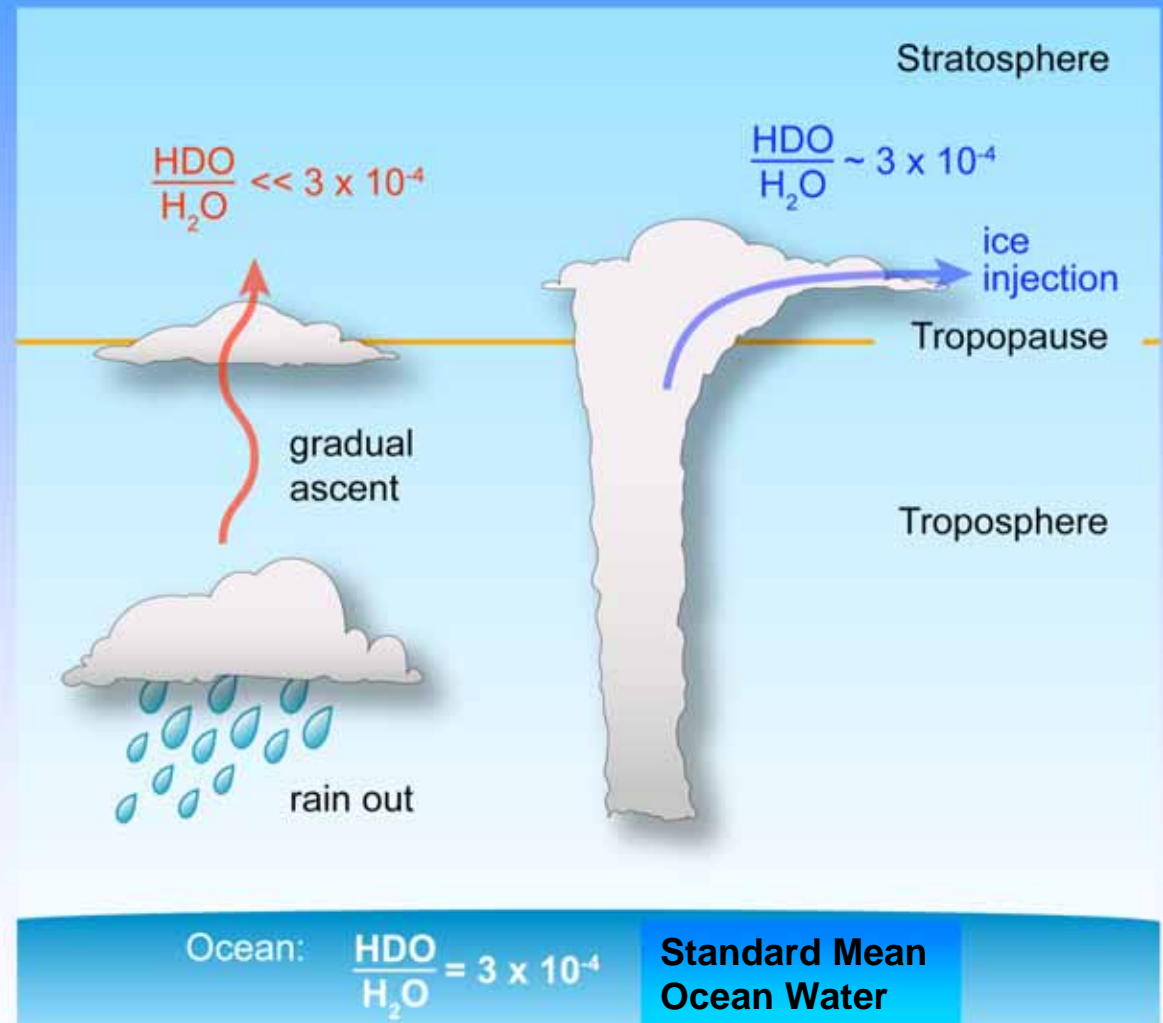
- Laboratory/airborne verification: Recognition of the fundamental importance of accuracy as a benchmark for intercomparison.
- Importance of independent methods used to diagnose systematic errors intrinsic to all observations.
- Sunshine policy on how raw data are converted to reported concentrations that are submitted to the archive.
- Key role played by head-to-head intercomparison flights.
- Need for a review board to critique field observations as is done with laboratory kinetics and photochemistry results.

Summary and Conclusions

- Stratospheric water vapor is an extremely sensitive indicator of the atmosphere's potentially rapid response to climate change
- Accordingly water vapor measurements with SI traceability are required for:
 - a. Establishing a temporal record of stratospheric water vapor
 - b. Satellite validation
 - c. Testing of strat-trop exchange mechanisms
 - d. Testing of climate models

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Storm Track July 7, 2005

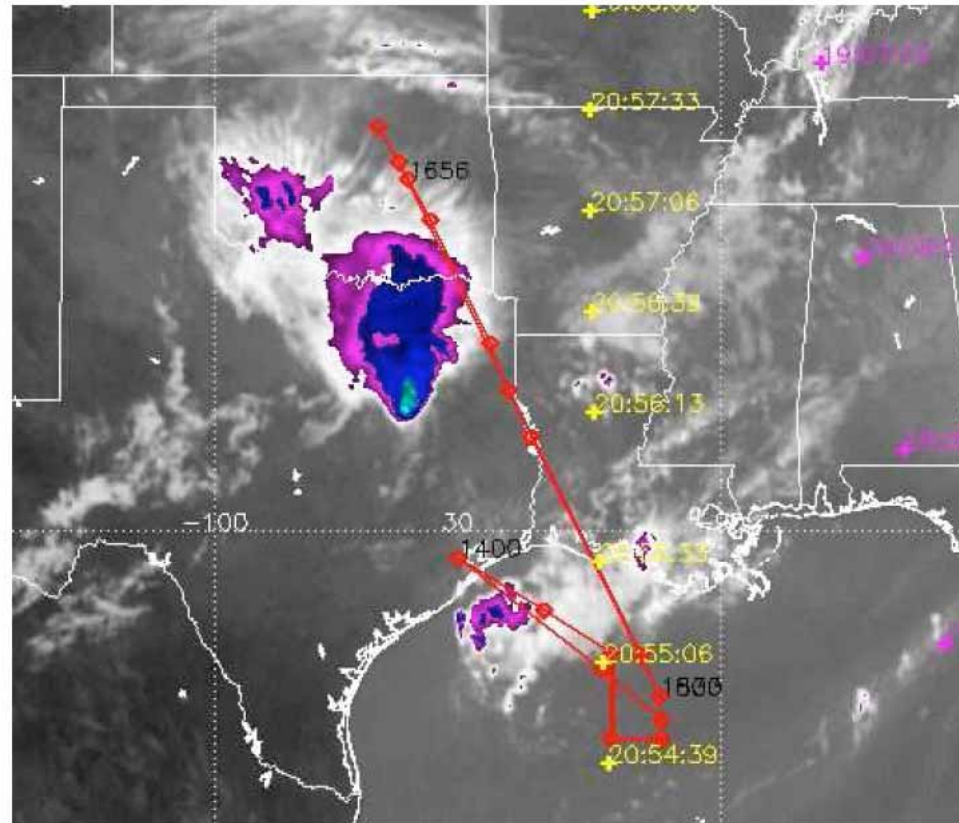
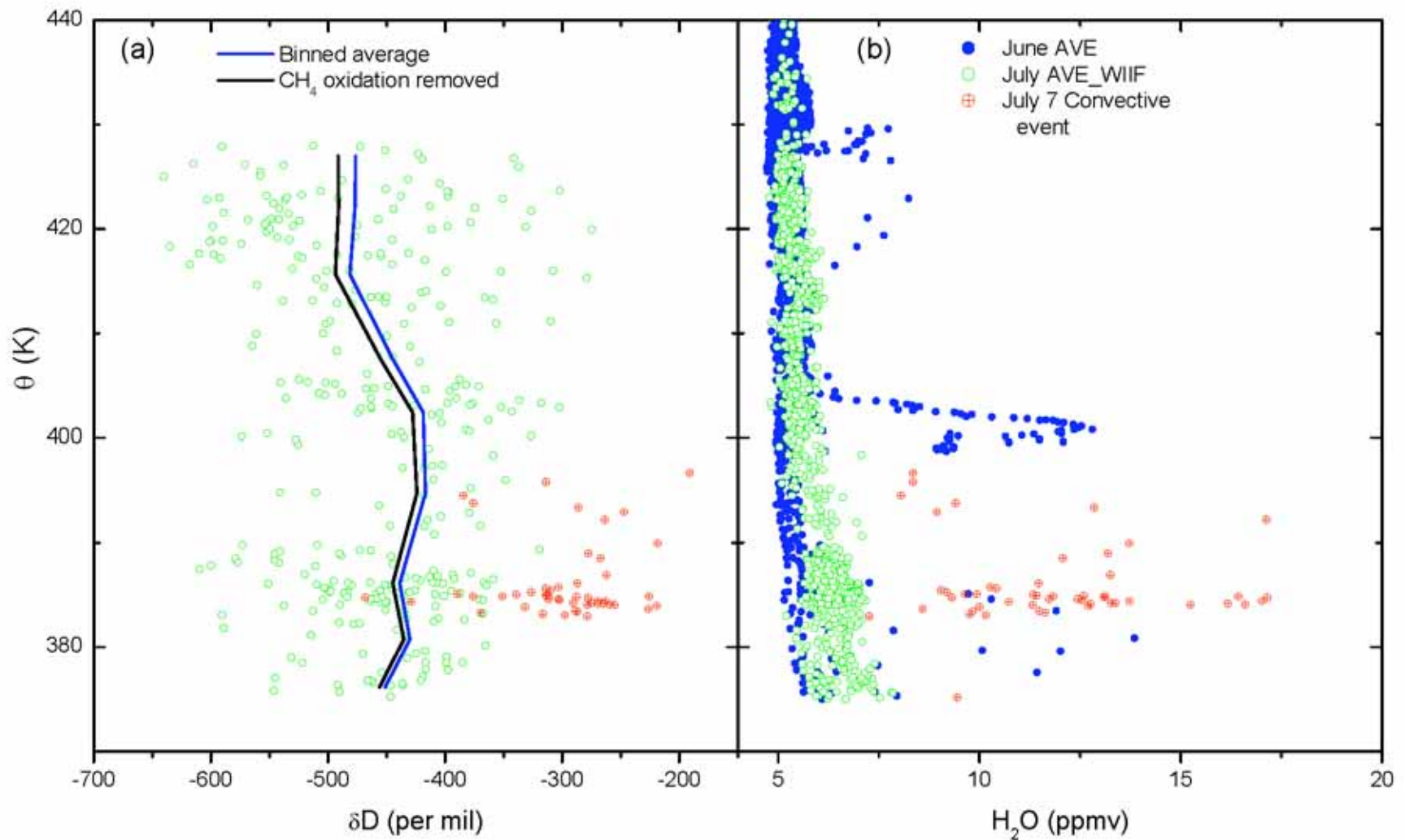
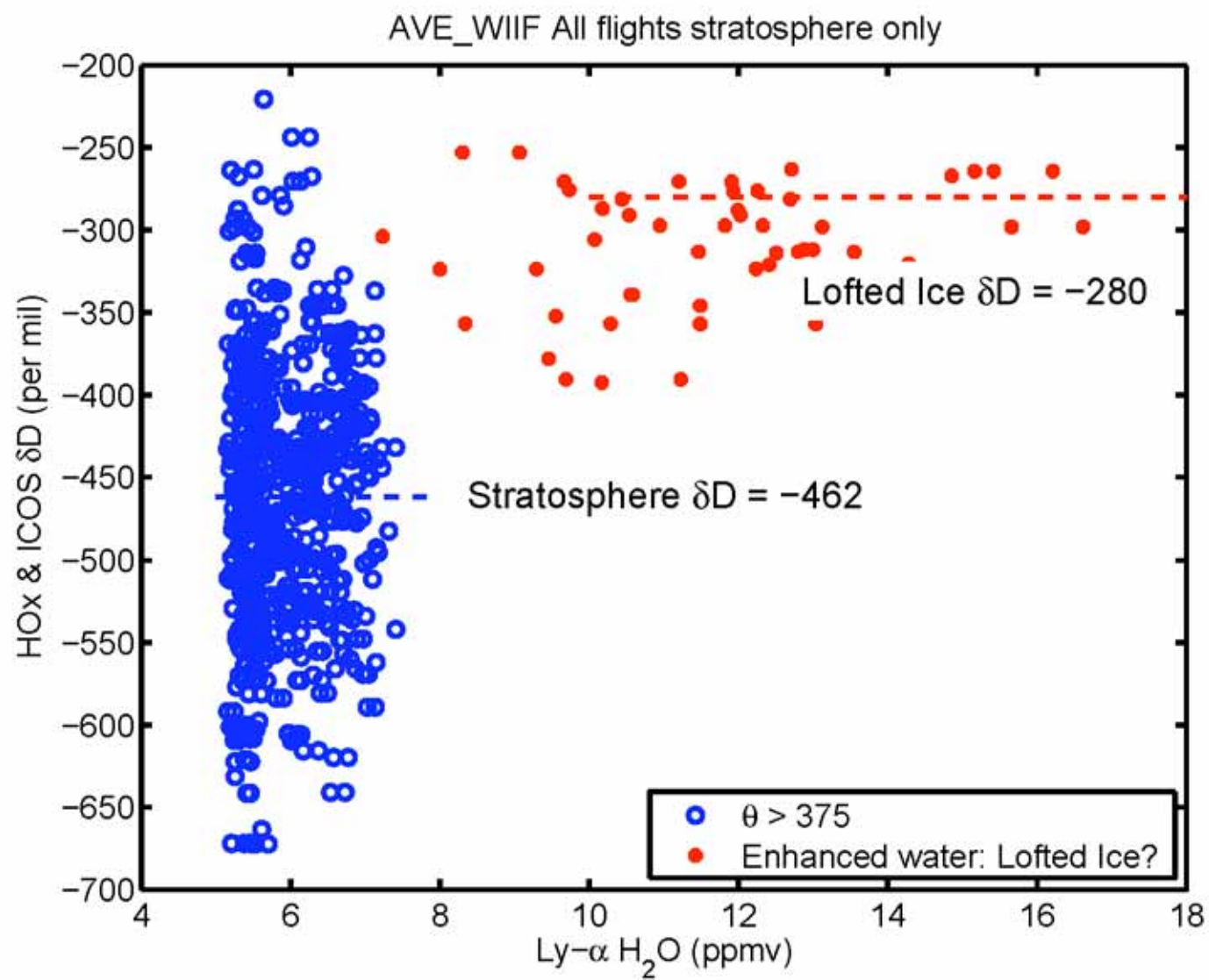


Figure 2: Flight track overlaid on the IR satellite image (Courtesy Lenny Pfister).

Overworld stratosphere water vapor





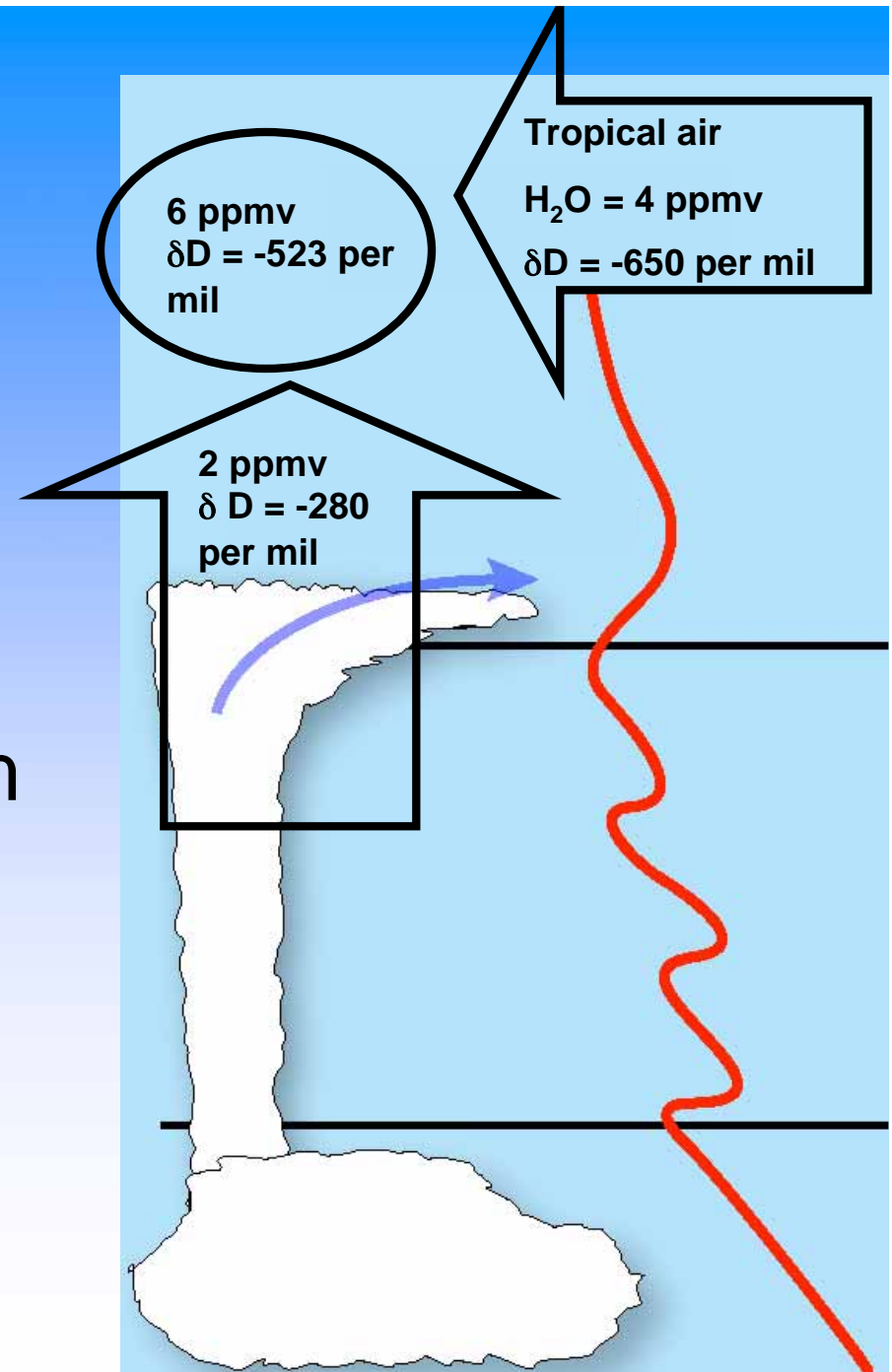
Isotopic depletion resulting from simple mixing

Rough calculation

Tropical source: 4 ppm
@ -650 per mil

Convected source: 2 ppm
@ -280 per mil

$$\delta D = 4/6(-650 \text{ per mil}) +$$
$$2/6(-280 \text{ per mil})$$
$$\delta D = -523 \text{ per mil}$$



What do isotopic measurements tell us about the mid-latitudes stratosphere?

In continental mid-latitudes summer:

- Stratosphere is isotopically very heavy, $\delta D \sim 450$ per mil
- Isotopic enhancements persist up to maximum altitude of WB-57 ($\theta > 420$ K)
- Water additions from convected ice are observed up to maximum altitude of WB-57 ($\theta > 420$ K)
- Mid-latitudes deep convection may be a significant source of water (isotopically heavy) to the overworld stratosphere